Clouds and the Earth's Radiant Energy System (CERES)
Validation Document

Surface and Atmospheric Radiation Budget (SARB)
Validation Plan for CERES Subsystem 5.0
(Compute Surface and Atmospheric Fluxes)

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5.1 Introduction

5.1.1 Measurement and Science Objectives

This document presents preliminary validation plans for the Clouds and the Earth's Radiant Energy System (CERES) retrieval of the vertical atmospheric profile of shortwave (SW) and longwave (LW) radiative fluxes: the surface and atmospheric radiation budget (SARB). SW is considered as any radiant energy whose source is the sun; LW is considered as any radiant energy whose source is thermal emission by the surface or atmosphere; by this definition, SW and LW slightly overlap in wavelength. The CERES effort to retrieve the SARB produces 3 sets of radiative fluxes as (a) the full vertical profile of fluxes in the atmosphere and at the surface, determined from radiative transfer calculations that match the simultaneously observed CERES top-of-the-atmosphere (TOA) fluxes, (b) an independent, parameterized set of radiative fluxes at the surface *only*, that are also simultaneous with the CERES TOA fluxes, and (c) the full vertical profile of fluxes in the atmosphere and at the surface as estimated for synoptic times (i.e., 3-hourly UTC). This document provides a brief overview of validation for all 3 sets of radiative fluxes, but it focuses on (a), which is produced by the Fu and Liou (1993) radiative transfer code. The vertical profile of fluxes is calculated with satellite imager-retrieved clouds and meteorological data as inputs, and the input parameters are tuned to match the observed CERES broadband TOA fluxes. The initial, untuned radiative transfer calculations generally do not match the observed CERES observations; the untuned fluxes at the surface and TOA are also archived for use in diagnostic studies of the radiative transfer techniques, the CERES cloud retrievals, and radiative forcing by aerosols, the surface, water vapor, and ozone.

The SARB is the primary driver of the hydrological cycle and the general circulation of the atmosphere. Anthropogenically induced changes in radiatively active trace gases and aerosols will affect the SARB, and will therefore force a climatic response. There are, however, formidable challenges to developing accurate SARB records in CERES, or in the Earth Observing System (EOS) generally. While certain components of the SARB can now be determined accurately with existing data, other components, to be determined with certainty, must wait for the development of active remote sensing systems on satellites, such as cloud profiling radars (CPR). CERES will be an unique opportunity to expand the space and time domain wherein the SARB can be specified accurately. The CERES program will not only provide accurate TOA broadband fluxes and simultaneous cloud property retrievals, but will also be well suited to determine the effects of clouds, gases, aerosols, and the surface on the various components of the SARB. The CERES SARB product will be an important tool for resolving the uncertainties in climate analysis and climate prediction that are associated with (1) feedbacks due to clouds, water vapor, snow, and ice and (2) anthropogenic forcings due to aerosols, surface albedo, and ozone.

5.1.2 Missions

CERES (Wielicki and Barkstrom, 1991) is a follow-on to the measurement of broadband TOA fluxes in (Barkstrom et al., 1989; Harrison et al., 1990). CERES will also simultaneously retrieve cloud properties with satellite imager data (Wielicki et al., 1995): the VIRS imager (similar to AVHRR) on the TRMM for 1997 launch and the more formidable MODIS on EOS-AM platform for 1998 launch and on EOS-PM (note Subsystem 4 ATBD and Validation documents). The calculation of the SARB, consistent with the measured broadband TOA fluxes and cloud property retrievals, will be a small component of CERES (Charlock et al., 1994a; Subsystem 5.0 ATBD).

5.1.3 Science Data Products

The SARB component of CERES retrieves the vertical profiles of SW and LW fluxes from the surface to the TOA. The most important parameters for SARB validation are the upwelling and downwelling fluxes at the surface, 500-hPa, tropopause, and TOA. As the experiment matures, fluxes will be validated at a larger number of vertical levels. The ratio of upwelling and downwelling broadband SW flux at the ground is the surface albedo. Unlike the surface spectral reflectance, the surface albedo is not a property of the surface only; surface albedo depends on the downwelling flux, whose spectral and directional characteristics are influenced by the atmosphere.

The SARB fluxes are produced by plane parallel radiative transfer calculations (Fu and Liou, 1993) using CERES cloud retrievals (based mostly on a narrowband imager) and other EOS data. The SARB fluxes are tuned to match the CERES broadband observed fluxes at TOA; the tuning determines a match to TOA fluxes within an anticipated uncertainty σ. A tuning algorithm is used to select which input parameters (i.e., cloud optical depth, surface skin temperature) are to be adjusted. The SARB results are sensitive to both the values of the input data used for tuning and to the apriori uncertainty (σ) for those parameters.

The assumed σ for the broadband observed fluxes are important, too. The SARB component of CERES validates the broadband flux profiles and the surface photosynthetically active radiation (PAR; 0.4-0.7 μm). The adjusted (tuned) cloud properties and cloud forcing to the broadband fluxes are also validated by CERES. The adjusted (tuned) values for other quantities, such as the humidity sounding and aerosol optical depth, are validated informally.

5.2.0 Validation Criterion

5.2.1 Overall Approach

The CERES approach to validating the SARB is based heavily on the use of data sets and programs which are not supported directly by EOS. For example, we use presently measurements of surface fluxes and other parameters which are collected by ARM. We interact with other programs, such as GEWEX, by providing carefully honed and readily accessible pre-launch CERES products to users who then effectively participate in CERES development, and eventually validation. This approach began with the CERES/ARM/GEWEX Experiment (CAGEX; Charlock and Alberta, 1996), a temporally intensive, limited area data set that is available online (http://snowdog.larc.nasa.gov:8081/cagex.html). CAGEX Version 1 provides a record of fluxes which have been computed with a radiative transfer code; the atmospheric sounding, aerosol and satellite-retrieved cloud data on which the computations have been based; and validating surface-based measurements for radiative fluxes and cloud properties from ARM.

Most of the data for post-launch validation of fluxes will be obtained from measurements in the ARM (DOE), the WCRP Baseline Surface Radiation Network (BSRN; DeLuisi, 1991; Gilgen et al., 1995), the NOAA Surface Radiation (SURFRAD; Hicks et al., 1995) programs and at the specially instrumented Walker tower near NASA Langley. EOS resources will be needed to purchase supplementary instruments for some of these sites. Measurements at perhaps 2-10 additional validation sites will have to be established by EOS, in order to cover desert and biomass burning regions. Helicopter measurements of surface properties and fluxes are needed to characterize the validation sites; a local exercise is in progress to guide such measurements, which are needed both before and after launch. Full validation of the within-the-atmosphere fluxes will require extensive sampling of fluxes from fixed wing aircraft (i.e., ER2, Egret, Twin Otter, Unmanned Aerospace Vehicle UAV). The financial resources for some of the surface-site, helicopter, and fixed wing aircraft operations have not been determined. Modest resources and organizational support for ship-of-opportunity cloud lidar and radiometer observations would appear to be extremely cost effective adjuncts to the validation of the surface radiation budget and cloud properties.

5.2.2 Accuracy of Current State of the Art

Estimates for the error in the TOA budget with ERBE (Barkstrom, 1989) range from about 5-8 Wm-2 for the net (SW+LW) budget for the global annual average to approximately 30-50 Wm-2 for the instantaneous footprint-scale SW flux, where the inversion process shows a strong dependence on the angular and dirctional model ADM (Suttles et al. 1988; 1989) and the scene identification (Wielicki and Green, 1988). Instantaneous errors in LW at TOA (the OLR) exceed 20 Wm-2 for clear skies in some conditions (Collins and Inamdar, 1995). In earlier "Version 0" CERES processing with ERBE, AVHRR and NMC data and the Fu-Liou (1993), Chou (1992), and Wang et al. (1991) radiative transfer codes, instantaneous footprint-scale errors of 50 Wm-2 for SW and 20 Wm-2 for LW were often found (see Figs. 13 and 16 of CERES ATBD 5.0). The near-synoptic viewing of 2.5o by 2.5o gridboxes from different angles (two ERBE satellites) indicates an rms error of 12-17% in the reflected SW flux. In a Release 1 exercise, the comparable standard deviation of ERBE (observed) fluxes with calculated fluxes was 15%.

On a monthly average for a 2.5o by 2.5o grid, it is often assumed that the ERBE fluxes are correct to within approximately 10 Wm-2 (Harrison et al., 1991). The error in the surface flux inferred from satellite data is larger. Using the algorithms due to Darnell et al. (1992) and Pinker and Laszlo (1992), the analyses in Whitlock et al. (1995) suggest that the rms error in the surface SW flux is roughly 20 Wm-2 for the monthly average for a 280 by 280 km equal area ISCCP (Rossow et al., 1991) grid; the bias is 10-15 Wm-2. Li et al. (1995a) use ERBE data and optimistically specify a smaller bias for the global mean surface SW flux. These estimates for the error in satellite-retrieved surface SW flux have met a significant challenge, however. Cess et al. (1995), Ramanthan et al. (1995), and Pilewskie et al. (1995) advocate a strong role for the absorption of SW radiation by cloudy skies; the cloud forcing of the absorption of SW radiation by the atmosphere is inferred to have a global mean value of 25-40 Wm-2; these results have been contested in turn by Hayasaka et al. (1995), Li et al. (1995b) and Chou (1995). There is at least one consensus on this issue, as many researchers infer that the global mean atmospheric absorption of SW radiation for total skies is at least 10 Wm-2 greater than the absorption predicted by radiative transfer applied to satellite-based data. A study of GCM codes (Wild et al., 1995) and the first CAGEX results (Charlock and Alberta, 1996) both indicate that calculated SW insolation for clear sky conditions significantly exceeds measured values. Given the overall controversy (see earlier discussion by Stephens and Tsay, 1990), it is premature to specify errors in the SW flux vertical profile at various levels within the atmosphere.

Gupta (1989) estimated the errors in the LW surface flux associated with errors in atmospheric parameters used to calculate the flux. Surface and atmospheric temperatures were assumed to have random errors of about 2.5 K, producing errors of 7-13 Wm-2 in the downward and net LW flux at the surface for a range of atmospheric soundings. The errors in preciptable water (PW) were taken as 30%; if we assume a PW error of 15%, the corresponding error in the downward and net LW surface flux would range from 2-9 Wm-2. An error of 50 hPa in the cloud base height would typically produce an error of 1-3 Wm-2 the surface LW flux; an error of 10% in cloud cover would typically produces flux errors of 2-10 Wm-2; both of these cloud-induced errors are much larger for low clouds in a cold atmosphere.

Errors for upwelling or downwelling LW fluxes within the atmosphere are comparable to those at the surface. The global mean total-sky and clear-sky OLR can be calculated to within 5 Wm-2 with ISCCP and sounding data such as TOVS, ECMWF, and GEOS-1 (Charlock and Rose, 1995). On a local basis, ISCCP errors in cloudiness can throw even the monthly average calculated OLR off by as much as 20 Wm-2. The largest systematic error in the calculation of clear-sky OLR is due to uncertainties in surface skin temperature and emissivity over arid regions; this can exceed 20 Wm-2 over the Sahara. Over most regions, the clear-sky OLR can be calculated much more accurately and be used to infer the climatically significant greenhouse effect.

Within the atmosphere, the divergence of LW flux is more physically significant than the net flux itself at an individual level. The divergence is usually expressed as a cooling rate. Uncertainty in the thickness and overlapping of cloudiness leads to an enormous uncertainty in the cloud forcing to the LW cooling rate of the atmosphere. With the atmosphere divided in even fairly thick vertical slabs of roughly 100 hPa, the error introduced by cloud overlap can exceed 0.25 K/day for a monthly average; this is 25% of the range of atmospheric LW cloud forcing (Charlock et al., 1994b). Systematic attempts to retrieve the vertical profile of fluxes have begun with operational satellite data (Stuhlmann et al., 1992; Ellingson et al., 1994).

Because of the great impact of rapidly varying cloud boundaries on both LW and SW divergence, an instantaneous estimate of divergence for a specific layer based on satellite data can have limited meaning. More credence can be obtained by integrating over time for thick layers. An expensive fixed wing aircraft program to validate the CERES SARB fluxes will be needed to establish the limits. We can be more confident above the cloud tops, however. CERES should be able to retrieve LW and SW fluxes at the tropopause (which is above cloud top) with confidence at all time scales, thereby providing a reliable net radiation budget for the stratosphere. If coupled with a thorough validation program over sites having detailed measurements of radiation and aerosol properties, the CERES retrieval of divergence could also be a confident result in the troposphere for clear skies.

5.2.2 Sampling Requirements

We focus on sites that measure multiple radiation parameters. Simply stated, long-term measurements have the best prospect for reducing the error in sampling, and the use of multiple parameters (i.e., SW downwelling, SW net, SW direct, UV-B, PAR, aerosol photometer, cloud lidar, etc.) permits us to determine the physics of the process and tighten the drum on tuning. Effective use of these non-NASA sites will depend on supplementary survey measurements (i.e., helicopter) by EOS. The Walker tower has been instrumented near NASA Langley to provide some of the validation directly and to prototype the survey activities. The tower is needed to provide a time history of net surface fluxes. Helicopter measurements will provide the SW spectral bidirectional reflectance function (BDRF), the directional characteristics of surface LW emission (Sellers and Hall, 1992), and the spatial variation of surface broadband fluxes about the tower. The BDRF is needed as an input to the radiative transfer codes that will be used to retrieve SW fluxes. The directional dependence of surface LW radiance must be known to accurately interpret satellite measurements, which in any particular instance are made from a single angle. The spatial variation of the surface fluxes will be used to translate the tower measurement to the corresponding satellite footprint.
Surface monitoring sites for CERES validation are placed in 3 categories
(see Tables 1, 2, and 3):

<u>Class 1</u> "Remote Sensing Physics" sites will be used to test the physics of CERES remote sensing and radiative transfer with a comprehensive description of atmospheric variables. The ARM Cloud and Radiation Testbed (CART) Southern Great Plains (SGP), North Slope of Alaska (NSA), and Tropical West Pacific (TWP) sites are in this category (see http://www.arm.gov/docs/sites.html). Class 1 sites will be used primarily to improve the absolute accuracy of CERES products. See Table 1.

<u>Class 2</u> "Regional Climate Trend" sites monitor a limited number of critical parameters. We will combine Class 2 site measurements with the satellite products to accurately describe regional secular changes in the radiative forcing of clouds, the surface, and aerosols. Surface monitoring at all Class 2 sites MUST include meteorology, broadband SW and LW fluxes, and aerosol optical depth (i.e., the MFRSR of Harrison et al., 1994); these measurements are needed to accurately "subtract the atmosphere" with MISR, MODIS, ASTR, and CERES data. Measurement of spectral SW, PAR, UVB, aerosol absorbing (physical and chemical) properties, and cloud condensation nuclei is required, as is the installation of cloud lidar (to 20 km, such as Spinhirne, 1993, MicroPulse Lidar), at a significant fraction of the Class 2 sites. We desire cloud radar and passive microwave measurements at a few Class 2 sites. If a secular trend is seen in the CERES retrievals, careful analysis with Class 2 time series with SARB radiative transfer will permit us to diagnose the approximate but distinct forcings of clouds, aerosols, ozone, and surface optics to that trend. Simultaneous, long-term measurement of multiple parameters is critical; they are needed to determine, for example, whether a weak trend in TOA reflection is due to an increase in thin cirrus contrails, a change in aerosol, or a change in the surface. This will enable us to quantify the current big mysteries in anthropogenic radiative forcing, namely regional changes in aerosols and land use. Experience with the modeling of climate perturbations from recent volcanic eruptions indicates that the signal of small changes to forcing can be detected and used quite effectively. NOAA Surface Radiation Budget SURFRAD (see http://www. srrb.noaa.gov/) and some WCRP Baseline Surface Radiation Network BSRN (see http://www.geo.umnw.ethz.ch/wrmc/) sites are in Class 2. A present land aerosol network (AERONET) coordinated by Brent Holben (brent@kratmos.gsfc.nasa.gov) would be suitable for Class 2, if AERONET added measurements of broadband surface radiation and initiated long-term monitoring at fixed sites. A present marine aerosol network (AEROCE) coordinated by Joseph Prospero would also be suitable for Class 2, provided that AEROCE included surface broadband radiative flux measurements. Long-term Class 2 deep ocean and desert sites are needed, and EOS may have to construct them.

Class 2 sites, when combined with MISR, MODIS, ASTER, and CERES data, will be used to parse and monitor trends in radiative forcing by aerosols and the surface. Class 2 sites will permit the effective screening of aerosols, thus opening a wide swath of EOS Land products to the prospect of long-term monitoring. Regional trends in aerosol are expected in many regions; without the aerosol screening by Class 2 sites, trends in many EOS Land products (i.e., absorbed photosynthetically active radiation, surface-leaving radiance, areal cover of vegetation) will be suspect to aerosol contamination. See Table 2.

Class 3 "Discrete Validation Sites" will be selected from those monitoring facilities with readily available and accurate measurements. Examples of Class 3 are those BSRN sites without aerosol photometers, the NOAA Integrated Surface Irradiance Study ISIS sites, and most of the Global Energy Balance Archive (GEBA) sites compiled by ETH in Zurich. Class 3 sites are essentially targets of opportunity that are established and run by other agencies. See Table 3.

Continuous, daily data from all 3 categories of sites will be used for CERES SARB validation. EOS field campaigns to measure the vertical profiles of fluxes with aircraft will be conducted at the Class 1 (ARM) sites. Field campaigns to measure surface optical properties from low altitude aircraft will be conducted at representative Class 2 sites. EOS must purchase supplementary monitoring instruments for some Class 2 sites. We have selected the Langley Walker Tower, SURFRAD, and BSRN as Class 2, rather than Class 3, largely because of our confidence that high quality, long-term monitoring of basic radiometric quantities will continue at these sites.

5.2.3 Measures of Success

The Suttles and Ohring (1986) survey of needs for the global SRB indicated that the desirable accuracies for surface SW and LW fluxes were +/- 20 Wm-2 for instantaneous and +/- 10 Wm-2 for a monthly average. The bias of surface SW flux in the current GEWEX SRB Project (Whitlock et al., 1995) exceeds 10 Wm-2; this was achieved only after a thorough round of algorithm intercomparison and extensive validation with ERBE TOA and GEBA surface measurements. This leads us to stress below the estimates of current uncertainty for SARB fluxes, rather than a subsequent prediction of higher absolute accuracy in EOS.
The rms error below is the total error (bias plus random) in the retrieval. Errors are given for Release 1 (ERBE) footprints as instantaneous for a typical daytime sun illumination and for 1.25x1.25 degree equivalent area gridboxes as a monthly mean. The monthly mean has sun half of the time, so SW bias errors for footprints are twice the bias errors for gridboxes; we have optimistically assumed that in going to the monthly-averaged grid, the application of geostationary data has modeled the diurnal cycle perfectly. Please note that these errors are the estimated differences that we expect to obtain *from measurements*. In the case of the ERBE TOA measurements, recall the suspected error (in the measurement itself) of 5-8 Wm-2 for the global mean. In the table below, TOA SW UP of "1:10" denotes a globally averaged difference *from ERBE* of 1 W/m**2 (sum calculated fluxes for all gridboxes for the month, difference from ERBE, divide by number of gridboxes). Because ERBE has an error ~ 5-8 Wm-2, the true error should exceed 1 Wm-2. In "1:10" the 10 Wm-2 denotes the rms error of the gridbox (difference each calculated gridbox flux from ERBE, square the differences and sum over all gridboxes, take square root and divide by number of gridboxes).

Tuned Atmospheric Flux Profile for Clear-sky (and Total-sky)
Anticipated for Pre-CERES Release 1 (October 1986 data)
Fluxes in Wm-2 as bias:rms

	Footprint Instantaneous (Daytime sun)		Gridded Monthly (24 hour mean)	
	CLEAR	TOTAL	CLEAR	TOTAL
Surface				
SW up	2:10	2:10	1: 5	1: 5
SW down	20:30	20:30	10:15	10:15

LW up	2:15	2:15	2:10	2:10
LW down	8:15	12:20	8:12	12:15
500 hPa				
SW up	5:30	10:30	2:10	5:10
SW down	20:30	20:30	10:15	10:15
LW up	8:15	12:20	8:12	12:15
LW down	8:15	12:20	8:12	12:15
Tropopause				
SW up	4:30	4:30	2:10	2:10
SW down	8:10	8:10	4: 5	4: 5
LW up	5:15	5:15	5:10	5:10
LW down	3: 5	3: 5	2: 3	2: 3
TOA				
SW up	2:30	2:30	1:10	1:10
LW up	1:20	1:20	1:10	1:10

In CERES on TRMM, EOS-AM, and EOS-PM, the TOA errors listed above may be achievable, because of superior CERES instrumentation. A successful SARB validation program is hoped to reduce the surface, 500 hPa, and tropopause errors to 1/2 the values listed above. This would mean a bias of 5 Wm-2 for the gridded, global mean surface SW insolation. An absolute accuracy of 5 Wm-2 is a challenge, even for the global mean, at the surface. However, with a vigorous Class 2 (Regional Climate Trends) validation program, we should be able to detect the *signal* of long-term aerosol- and surface-induced *perturbations* to better than 5 Wm-2, in clear sky conditions, for individual gridboxes with surface monitoring sites. With ~50 Class 2 sites, the signal of secular aerosol and surface albedo changes to climate could be mapped at course spatial resolution. With fewer (~10) Class 2 sites, we would likely miss signals due to changes such as de-industrialization in Western Europe, desertification in the Sahel, and the reduction of Amazon forests.

5.3.0 Pre-launch algorithm test/development activities

5.3.1 Field Experiments and Studies

Confidence in a retrieval of the full profile of the SARB is limited by issues concerning (a) the technique applied for broadband radiative transfer, (b) the input data used in the retrieval, and (c) the measurements available for validation. Regarding formal radiative transfer (a), we note the efforts of the Intercomparison of Radiation Codes in Climate Models (ICRCCM; Ellingson and Fouquart, 1990; Ellingson et al., 1991) and the Spectral Radiation Experiment (SPECTRE; Ellingson and Wiscombe, 1995) to test and advance techniques. Significant problems in atmospheric radiative transfer remain, however, even for some of the most ubiquitous conditions. For example, in the case of surface SW insolation for clear skies, the fluxes calculated with widely-used GCM codes are significantly biased when compared with measurements (Wild et al., 1995). In retrievals of flux profiles with cloudy skies, the input data used in the retrieval (b) can easily be misinterpreted (i.e., Wielicki and Parker, 1992). The input data on cloud optical properties are dependent on the validity of radiative transfer again, but here in the narrowbands of the satellite radiometer. It is a further challenge to obtain satisfactory calibration for the satellite instrument itself (i.e., Brest and Rossow, 1992). To validate a retrieval of the SARB within the atmosphere (c), there are only a few measurements of radiative fluxes by aircraft. In addition, natural meteorological variability poses a formidable barrier to the interpretation of any record of the vertical profile of radiative fluxes that is available for validating a retrieval. For example, Hayasaka et al. (1995) have shown how readily the multidimensional effects of clouds can confuse the absorption inferred from a simultaneous record of SW fluxes at two different flight levels.

In an attempt to address these and related difficulties, we have placed a virtual cage over a small area that is well-instrumented and begun a long-term, collaborative effort to calculate, observe, and interpret the broadband SW and LW fluxes that drive the physics of climate (Plate 1). The cooperative CERES/ARM/GEWEX

Experiment (CAGEX) is a public access set of input data, calculated fluxes, and validating measurements over the Department of Energy Atmospheric Radiation Measurement (ARM; Stokes and Schwarz, 1994) Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) site in Oklahoma, U.S.A. Version 1 of CAGEX uses a 3 by 3 grid (0.3o on each side) every 30 minutes from 1409 UTC to 2239 UTC (daylight) for 26 days, starting on April 5, 1994. CAGEX Version 1 now provides on-line access (see http://snow-dog.larc.nasa.gov:8081/cagex.html) to:

(1) satellite-based cloud properties and atmospheric sounding data that are sufficient for broadband radiative transfer calculations;

(2) vertical profiles of radiative fluxes calculated with that data as input; and

(3) validating measurements for broadband radiative fluxes and cloud properties.

See Plate 1 and Figure 1. Successive versions of CAGEX will revisit the same area and seek incremental advances in the quality of the cloud, aerosol, sounding and surface optical property data, the calculated fluxes, and the measurements of fluxes and atmospheric radiative properties.

CAGEX is a community window for CERES research on the SARB. With the present generation of satellite sensors and broadband radiative transfer codes, the full profile of the SARB cannot be determined with sufficient accuracy in many cases. CERES aims to (a) extend the domain over which the SARB can be determined accurately, (b) quantify the uncertainty in other areas, and (c) use a comparison of computed and observed broadband TOA fluxes as a diagnostic of both radiative transfer techniques and the CERES satellite-based cloud properties.

CAGEX will be continued beyond the April 1994 domain of Version 1. CAGEX Version 2 will cover the ARM Enhanced SW Experiment (ARESE; September 25, 1995 to November 1, 1995). ARESE targets the absorption of SW radiation by the troposphere under both clear and cloudy conditions. A unique aspect of ARESE is the measurement of broadband SW fluxes by 3 aircraft (a Twin Otter below 2 km, an Egret at 13 km, and an ER-2 at 20 km). We will include surface radiometric measurements which were made at several sites and also plan to include aircraft-measured fluxes. Airborne measurements were made for a fraction of ARESE, but the CAGEX calculations will be extended to 24 hours per day. Soundings will be obtained from two sources, the special cluster of 3-hourly ARM radiosonde launches and the NCEP mesoscale Eta model output (Yarosh et al., 1996). The water vapor profiles will be studied, and perhaps adjusted, with surface-based Raman lidar (Melfi et al., 1989) and 6.7 μm satellite soundings (Soden et al., 1994). Minnis et al. (1995) intend to provide histogram statistics of the pixel-scale satellite radiances and cloud properties within each 0.3o by 0.3o gridbox. A comparison of the radiative diabatic heating profiles from CAGEX and the Eta model will made available.

The analysis of ARESE aircraft measurements of fluxes will be vital for CERES. They will be used to set the sampling pattern for expensive post-launch validation flights for the CERES SARB over the ARM CART SGP, NSA, and TWP sites. The ER-2 and Egret fluxes will be very closely compared the CAGEX Version 2 calculations; we must establish whether the bias of computed clear-sky insolation (w.r.t. measurements), now well-established at the surface, extends to the tropopause.

An expanded area, 0.5o by 0.5o run of CAGEX Version 3 will cover April 1996 continuously through September 1996 at the explicit request of the GEWEX Continental-Scale International Project (GCIP; see WCRP, 1995), a hydrology-oriented program. Accuracy will not be as great as in the immediate vicinity of the ARM SGP CART site, which will retain a concentration of data and effort, but feedback on the CERES pre-launch products will be obtained from a diverse research community. NOAA SURFRAD (SURFace RADiation; Hicks et al., 1995) will provide aerosol optical depth and validating measurements for fluxes at other sites.

CERES plans to conduct a surface optical property experiment over the SGP site during 1996 or 1997, measuring the surface SW broadband albedo, SW spectral bidirectional reflectance, and the angular dependence of LW window radiance with a helicopter (Whitlock et al., 1994); a preparatory airborne experiment has been conducted over Virginia to support this. The survey of surface radiative characteristics in FIFE (First International Satellite Land Climatology Project Field Experiment; Sellers and Hall, 1992) provides impetus to take similar measurements over the SGP site. These measurements will be used in tests of CERES algorithms for retrievals of the SARB. Present CERES global Release 1 and local area CAGEX algorithms use simplified surface optical properties based on Briegleb et al. (1986).

We advocate CAGEX as a useful complement, regularly spanning a grid for many time steps, to the more focused but smaller domain activities planned by SPECTRE. CAGEX is a test of the remote sensing of the spatial and temporal variations in broadband flux, as well as instantaneous radiative transfer. The radiative "noise" induced by a rapidly changing 3-D cloud field can be enormous (i.e., Cahalan et al., 1994, Hayasaka et al., 1995). Such an integrating experiment is needed to establish accuracy bounds for present means of determining radiative flux.

5.3.2 Operational Surface Networks and Existing Global Satellite Data

Surface radiation observations are being collected for validation of the global scale, pre-launch CERES Release 1 exercise with retrospective ERBE, AVHRR, and NMC Reanalysis data covering October 1986 and December 1986-January 1987. Daily SW insolation has been collected at 482 sites for Release 1 and will be matched with daylight-average cloud fraction from ISCCP C1. For October 1986, we have the access to a unique record of the FIRE pyranometer array (instruments separated by 15-220 km) over Wisconsin. The Release 1 surface radiation will be compared with the GEWEX SRB Project (Whitlock et al., 1995), which use ISCCP satellite data and the GEBA compilation for validating surface measurements.

5.4.0 Post-launch Activities

5.4.1 Planned Field Activities and Studies

Post-launch validation in the CAGEX activity will expand to cover two additional ARM sites, the Tropical West Pacific (TWP) and North Slope of Alaska (NSA). Like the current ARM SGP site, the TWP and NSA sites are anticipated to have comprehensive measurements of surface fluxes, soundings, and some optical properties of clouds and aerosols. When combined with field campaigns for fixed wing aircraft measurements of fluxes, cloud properties, and detailed helicopter measurements of the spectral and directional optical properties of the surface, the ARM sites will be ideal for the synergistic validation of CERES, MODIS, MISR, and ASTER. The SGP, TWP, and NSA sites may have sufficient meteorological variability to permit a study of most of the cloud types that are found around the globe.

There will be many opportunities to validate the input sounding parameters from GEOS-1 (Schubert et al., 1995) after launch. Comparisons of the temperature fields among NCEP, ECMWF, GEOS, and the UKMO are becoming mature. For the SARB, the humidity profile is a more critical parameter. EOS-AM will not have a microwave instrument for retrieving humidity. The humidity profile in the GEOS data will be carefully compared with GVap products which will use SSM/I. Unfortunately, most global sounding data lacks correlative information on radiation and clouds. The combined validation of radiation and soundings will be emphasized over the data-rich ARM SGP, TWP, and NSA sites.

Validation of fully geographically representative surface radiative fluxes, surface optical properties, and aerosol effects for CERES will be more difficult. The optical impacts of surfaces and aerosols are weaker than clouds, but they are subtle and highly regionally dependent. The anthropogenic impacts on surfaces and aerosols are today the largest uncertainties in climate forcing. CERES SARB pre-launch algorithms specify aerosol single scattering albedo and asymmetry parameter from d'Almeida et al. (1991) tables. CERES will focus on the limited number of long-term, high quality radiometric measurements made by the NOAA Surface Radiation (SURFRAD) network in the U.S. and by the World Climate Research Program (WCRP) Baseline Surface Radiation Network (BSRN) at a few score sites around the globe. BSRN and SURFRAD generally do not provide soundings, but those BSRN and SURFRAD sites with aerosol photometers and cloud lidars will provide extremely useful data for CERES SW validation. While BSRN and SURFRAD do not explictly measure aerosol absorption, it will be possible to estimate aerosol absorption from a limited number of physical and chemical measurements made under the aegis of the International Global Atmospheric Chemistry IGAC program at a few SURFRAD and BSRN sites. The CERES clear-sky energy closure problem (i.e., are the long-term trends in surface and aerosol properties, as detected by other EOS sensors, having the anticipated impact on fluxes?) will be worked at these sites. When clear-sky closure is achieved to an acceptable degree with BSRN and SURFRAD, CERES will be placed to use the total-sky surface fluxes at these sites for validating within-the-atmosphere cloud forcing at a wider geographical range than just the 3 ARM sites (SGP, TWP, and NSA).

The major drawbacks to the effective exploitation of meaurements of the accurate broadband surface radiometric fluxes in BSRN and SURFRAD are the limits to the correlative data; these sites must be upgraded from "Class 3" to "Class 2." Adding correlative measurements (i.e., MFRSR for cloud and aerosol optical depth, cloud lidar, and spectral SW) is more important than increasing the numbers of surface sites (beyond those projected by BSRN and SURFRAD) or the placement of the surface radiometers on very tall (>100 m) towers. Validation of biologically relevant fluxes in limited spectral bands can be provided if the surface sites measure Photosynthetically Active Radiation (PAR) and UV-B. Helicopter surveys of the spectral SW BDRF and upwelling broadband SW and are needed to fully close the clear-sky SW radiation. Such helicopter surveys of the surface SW optical properties will complement both the satellite-based (EOS) and ground-based (ARM, BSRN, SURFRAD) programs; helicopter surveys will permit for the screening of surface effects in satellite data and thereby aid in determining the optical properties of thin clouds like cirrus; when combined with ARM soundings and aerosol measurements, they will enable EOS to subtract the atmosphere when retrieving surface properties. At this writing helicopter surveys of high reflectivity surface regimes like deserts and snow fields, where the retrieval of surface fluxes with satellite data is most difficult, have not been planned. Effective validation of LW emissivity and surface flux is not possible without helicopter surveys of the directional dependence of surface spectral radiance and of the spatial dependence of LW fluxes. Even with an EOS-supported upgrade from Class 3 to Class 2, LW validation at BSRN and SURFRAD sites will be hampered by the lack of atmospheric sounding data.

The AEROCE (aerosol) stations and only a few BSRN (radiation) stations will cover the oceans (see previous Section 5.2.2). Hence oceanic validation will rely partly on field campaigns, primarily as targets of opportunity. It is advisable for EOS to have sufficient resources to "piggy back" small radiation measurements on suitable oceanographic cruises. Earlier Tropical Ocean Global Pacific Experiment (TOGA) Coupled Ocean Atmosphere Response Experiment (COARE) data is presently used in tests of CERES SARB SW surface insolation algorithms. Before launch, we will also test algorithms with the Central Equatorial Pacific Experiment (CEPEX) March-April 1993 database, which is available through the CEPEX Information Data System (CIDS; http://borneo.ucsd.edu/). Unfortunately, the observational program of the World Ocean Circulation Experiment (WOCE) is scheduled to conclude in 1997, before the launch of EOS-AM. We will use radiation data from other ocean campaigns when available. Note the ship of opportunity proposal in Section 5.4.3.

Because of the importance of snow-albedo feedback to climate, and because of the difficulty in retrieving surface fluxes over snow with satellite data, a field campaign to validate CERES surface fluxes will be needed in a snowy region. GCIP (1995-1999) will have a Large-Scale Area Northwest (LSA-NW) focus on the NW sources of the Mississippi River in 1998-1999 and would be an appropriate vehicle for such a campaign in conjuction with the SURFRAD site in Fort Peck, Montana or the BSRN site at Bratt's Lake, Canada (50 deg 12 min N, 104 deg 43 min W). LSA-NW has large seasonal and interannual variations in snow cover. Validation over permanent Arctic snow cover and seasonal sea ice will be conducted in concert with ARM NSA and SHEBA.

Validation of the CERES fluxes within the atmosphere will depend mostly on the confidence of valiation at the surface and TOA. An extensive measurement program of within-the-atmosphere fluxes from fixed wing aircraft is sorely needed; ARM plans to conduct only a small number of flights. Measurements of fluxes at the tropopause should assume the highest priority. The tropopause flux is important for climate, and it is a tractable retrieval problem because it is above the cloud tops. Below the tropopause, CERES will attempt to validate the within-the-atmpsphere broadband fluxes in conjuction with a simulation of narrowband fluxes in the spectral bands of the EOS imagers. Pioneering this concept in pre-launch Release 1, the Kratz (1994) correlated ks will be coupled with the Fu-Liou code used by SARB in the 5 channels of AVHRR. This will be a more viable approach with EOS-PM, which will have AIRS.

The greatest challenge in CERES validation is posed by the flux below cloud top. Measurements are infrequent (except at the surface). Below the cloud tops, one has less confidence in the CERES retrieval of cloud properties. A Cloud Profiling Radar (CPR) is essential for monitoring geometrical layering of clouds. CPR will be deployed over the ARM sites. The complete valiation of CERES awaits the deployment of a space-borne CPR. For thin optical depth clouds, it is possible to obtain this information from surface micropulse lidar (Spinhirne, 1993) or satellite-based cloud lidar like GLAS.

CERES Co-I Dominque Crommelynck (Royal Meteorological Institute of Belguim) is testing a balloonborne package for direct, in-situ measurement of radiative flux divergence. Plans for the post-launch application of this platform are not firm at present, because it is at an early stage of development. The balloon platform has great potential for the interpretation of CERES SARB retrievals.

5.4.2 Needs for Other Satellite Data

As EOS matures, more highly processed data from MODIS will permit the validation of CERES retrievals of aerosol loading, surface emissivity, and skin temperature. SAGE III will provide a validation for stratospheric aerosols and some radiatively active stratospheric gases. The MISR surface BDRF will be used to validate the CERES models of surface optical properties.

5.4.3 Measurement Needs

The need for special surface measurements was noted in Section 5.2.2: supplementary monitoring for spectral radiation, aerosol properties, and cloud base height at the Class 2 "Regional Climate Trend" sites. We assume that EOS will negotiate suitable agreements for access to network (ARM, SURFRAD, BSRN, GEBA) measurements.
Validation over the oceans will be problematic. At this writing, the BSRN island sites at Bermuda and Kwajalien do appear to provide data that represents the atmosphere over the surrounding ocean. Even with ARM TWP and BSRN, we are not likely to have representative time series over the global ocean at more than a few such sites. CERES is not suited to guide a ship of opportunity program, but one is needed. Some instruments could be automated for shipboard use. A Spinhirne (1993) MPL would be valuable as a survey instrument, simply because we have so little hard data on ocean cloud base, which is a significant uncertainty factor in the surface LW budget. If adequate level-sensing and recording technology could be deployed on ships of opportunity, a full battery of broadband radiometers and aerosol photometers would also be practical.

5.5.0 Implementation of Validation Results in Data Production

5.5.1 Special CERES Validation Data Products

Some of the SARB validation will be conducted with standard data products, rather than the special validation products described in below. The special validation products will be intensive, at least for a start. After some post-launch results are analyzed in detail, we may switch to a less intensive routine over a larger number of sites. The procedures described below will be used to test the full vertical profile of raditive fluxes, as computed with the Fu-Liou (1993) code and tuned to match CERES observations at the TOA (Subsystem 5.0), and also the "surface-only" retrievals (Subsystem 4.6) in the LW (Inamdar and Ramanthan, 1995; Gupta et al., 1992) and SW (Li and Leighton, 1993). We presently have the software to simulate Fu-Liou fluxes in the narrowbands of the AVHRR channels, as well as the broadband SW and LW ERBE. At launch, we will be ready to simulate the CERES 8-12 μm window, VIRS, and key MODIS channels, too. Some CERES jargon (ATBD Subsystem 5.0) is used in this Section: MOA (Meteorology, Ozone, Aerosol) is the atmospheric sounding data used for radiative transfer calculations; SSF is a CERES product on an instantaneous ERB footprint, which contains numerous simultaneous cloud imager footprints; FSW is a 1.25 deg equivalent area gridded CERES product, to the nearest hour of the instantaneous ERB footprint; SYN is a CERES 3-hourly synoptic product, based heavily on narrowband operational ISCCP B-3 data which has been processed to be more consistent with the CERES ERB and CERES cloud imager (VIRS on TRMM and MODIS on EOS-AM) data.

5.5.1.1. Input

For each CERES footprint covering the Walker tower (near NASA Langley) and all suitably equipped ARM, SURFRAD, and BSRN sites (at ~50 sites), the SSF and the cloud property data for every imager pixel is required (SSF has the footprint-scale ERB data and cloud retrievals) , as is the stream of MOA data associated with each footprint; a duplicate set is needed for the CERES SSF footprint that is the NEXT closest to all suitably equipped ARM, SURFRAD, and BSRN site. We expect the DAAC provide access to an abbreviated record of data from the ARM sites and the full records from suitably equipped SURFRAD and BSRN sites. The MOA data will be based on GEOS (Schubert et al., 1995) and we request that DAAC also provide the output of the nearest gridbox of the NCEP assilimation system. For the 1.25o equivalent area gridboxes that contain each of these sites, we will use the full SSF and MOA outputs that correspond to the instantaneous CERES scan or the regular 3-hourly geostationary-based scan. For each footprint within those 1.25o boxes, we will use the full SARB output at all vertical levels.

For validating the 3-hourly gridded synoptic product (SYN), the SARB WG anticipates a continued collaboration with the CERES Cloud WG in running a CAGEX-like activity over the ARM SGP site. CAGEX may be extended to the ARM TWP and NSA sites; possibly to suitably equipped SURFRAD and BSRN sites if the software can be handled with available resources. We expect that the DAAC will provide access to the needed operational satellite data for CAGEX on a half-hourly basis.

Validation of the FSW and 3-hourly SYN, the SARB WG will require the FSW and SYN outputs at all vertical levels over the ARM sites and the suitably equipped SURFRAD and BSRN sites. The validation efforts of both SARB and Cloud WGs would be boosted if pixel-scale cloud and TOA retrievals were provided for 3x3 nests of operational imager pixels nearest the ARM, SURFRAD, and BSRN sites.

The most novel aspect of CERES is perhaps the retrieval of the full vertical profile of radiative fluxes. Validation requires a costly fixed wing aircraft program over the ARM and other sites. We will be better placed to give the requirements for such a flight program after some analysis of ARESE data (which operated September 26 - November 1, 1995).

If EOS fosters a ship of opportunity program (see section above), software would be needed to track the ships and output CRS (the SARB retrieval on each instantaneous ERB footprint is stored in CRS), FSW (gridded 1.25o by 1.25o product to nearest hour), and SYN (gridded 3-hourly synoptic estimate) data.

5.5.1.2. Output

A CRS-plus output will be produced (all fluxes at all levels with tuning) for each footprint (ARM, SURFRAD, BSRN) above for comparison with the standard output. The CRS-plus output will contain the broadband fluxes and the fluxes in the narrow bands of the cloud imager (we have the correlated ks to do this with AVHRR, for example). For each set of narrowband radiances of the cloud imager, an estimated narrowband flux will be produced by applying the ADM of the closest CERES broadband channel. As resources permit, more comprehensive software will be developed to simulate spectral and directional radiances of additional ground-based and satellite-based measurements.

5.5.1.2.1. CRS-plus calculation by SARB will discard the point spread function (PSF) weighting of pixel scale cloud retrievals in the footprint. This will test the application of the PSF to the imager data.

5.5.1.2.2. CRS-plus calculation will tune the two adjacent footprints as a single footprint. This will test the spatial resolution of the broadband footprint data.

5.5.1.2.3. CRS-like calculation will isolate the cloud imager retrievals symmetrically around the validation sites and perform a "forward only" (untuned) radiative transfer calculation. This seeks a more accurate match to the instantaneous observed surface fluxes.

5.5.1.2.4. CRS-plus calculation will increase the number of cloud catgories (currently there are no more than four) used in SARB tuning. This independent pixel calculation will seek a higher accuracy for the fluxes within the atmosphere.

5.5.1.2.5. CRS-plus calculations will tie the SARB tuning to both the CERES TOA and to the radiative fluxes observed at the surface.

5.5.1.2.6. Series of CRS-plus calculations will use different surface and atmospheric input data (i.e., hypothetical overlap conditions for clouds, tower-measured snow albedo, GEOS temperatures, surface-based microwave humidity, lidar cloud heights, photometer-based aerosol optical depth).

5.5.1.2.7. Series of CRS-plus calculations will change the number of variables allowed for tuning; currently we allow three atmospheric parameters to vary.

5.5.1.2.8. Series of CRS-plus calculations will change the σs (uncertainty parameters) used in the tuning. These will include tests with zero σ for the CERES observed TOA fluxes; tuning for an exact match to CERES TOA data.

5.5.2 Validation Procedures and Milestones

The first validation will be global surveys that are based on readily available ancillary data sources. For example, a validation of the tuned SST will begin by simply comparing with alterative global SST data sets. Rudimentary validation by global-scale survey will continue as EOS matures. The MODIS team on EOS-AM, for example, will retrieve aerosol optical thickness; this will be compared with the CERES tuned aerosol optical thickness based on TRMM and EOS-AM tuning.

The SARB radiative transfer and tuning algorithms will be examined using the outputs in 5.5.1.9 above and focusing primarily on the sites with ARM, SURFRAD, and BSRN data. This analysis will be based primarily on CRS and will be used to make fundamental changes, if needed, to the SARB algorithms. Cloud WG algorithms and MOA inputs may also be altered, based on an analysis of CRS time series. The results will certainly influence the rate at which data is issued at supplementary levels in addition to the standard surface, 500-hPa, tropopause, and TOA.

The validation for FSW and SYN will not involve specialized processing as for CRS above. Gridded FSW and SYN cloud, MOA and SARB products will be compared directly to the measurements at the ARM, SURFRAD, and BSRN sites. SYN is a 3-hourly product, and we will compare it carefully with the half-hourly based CAGEX retrievals over the ARM sites and suitable SURFRAD and BSRN sites. Time series analysis will be used to determine the quality of CERES inputs and outputs and to assess the space and time averaging algorithms. Nested 3x3 pixel-scale 3-hourly inputs will permit a determination of the quality of SYN cloud and radiation retrievals directly over the surface sites.

If supplied with fixed wing aircraft flux measurements, the SARB WG would make a detailed comparison of CRS, including a pixel-based analysis based on CERES data (5.5.1.9.1 above) and a temporally intensive pixel-based analysis based on CAGEX and operational satellite data.

The ultimate goal of the SARB WG in CERES is the retrieval of the full vertical profile of radiative fluxes. While we will eventually have confidence in the retrievals at some levels such as the tropopause, the full profile is a formidable charge. Validation of within-the-atmosphere fluxes will not stop. Rather, we will try to automate the validation process. The initial use of validation will be a check on CERES remote sensing. If we lack adequate fixed wing aircraft data, the checking of fluxes inside the atmosphere will be necessarily exhaustive but heavily inferential. The lack of fixed wing aircraft data for validation for CERES would delay the release and confident application of a valuable climate data set. As CERES matures, continued validation over the ARM, SURFRAD, and BSRN sites and new measurements and field campaigns will be used to make accurate diagnoses of the trends in climate parameters; aerosol forcing; changes in surface optical properties; radiative response to climate change.

5.5.3 Role of EOSDIS

EOSDIS will set up the software for validation procedures outlined in Section 5.5.2. This will be a formalization of the validation procedure now being tested in CAGEX. Initial validation results will be made available on the WWW by the CERES Science Team. A standard, production type of validation will be executed by EOSDIS.

5.6.0 Summary

Our goal in this component of CERES is to extend the spatial and temporal domain over which the Surface and Atmospheric Radiation Budget (SARB; the vertical profile of radiative fluxes) can be specified with useable accuracy.

CERES validation is already underway in the CERES/ARM/GEWEX Experiment (CAGEX). CAGEX Version 1 (Charlock and Alberta, 1996) provides on-line access to the input data for the pre-launch SARB retrievals, the retrieved fluxes, and validating measurements over the ARM CART SGP site (http://snowdog.larc.nasa.gov:8081/cagex.html). For post-launch validation, CAGEX will be extended continuously to the ARM CART TWP and NSA sites. The ARM sites are regarded as Class 1 "Remote Sensing Physics" sites. See Section 5.3.1 and Plate 1 for a description of CAGEX and Section 5.2.1 for a description of Class 1 sites.

An extensive campaign of aircraft measurements will be needed to validate SARB fluxes over the ARM CART sites. This will be expensive. The requirements for it will be set by an analysis of ARESE data in CAGEX Version 2.

A unique Class 2 "Regional Climate Trend" set of validation sites is proposed for EOS-wide application (see Section 5.2.1). Class 2 sites are based on existing or planned networks outside of EOS, but supplementary EOS measurements are needed. Class 2 sites include surface radiometry, the measurement of aerosol optical depth, and cloud lidar; this suite of instruments enables a researcher to validate the "subtraction of the atmosphere" by EOS. By combining MISR, MODIS, ASTER, and CERES TOA measurements and SARB calculations with Class 2 data, we will be able to accurately distinguish and monitor trends in the elusive climate forcings of anthropogenic aerosols (Penner et al., 1994) and land use changes. Current climate forcing assessments (see IPCC 1990 and subsequent documents in series) are very weak on aerosols and surface albedo. The Class 2 sites would be able to monitor the impact of the direct effect of aerosols (scattering and absorption), but not necessarily the indirect effect of aerosols (cloud nucleation; i.e., Twomey, 1977).

Special validation software and testing is described (Section 5.5.1).

Routine validation will be conducted at Class 3 sites, which are essentially targets of opportunity.

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Table 1

CLASS 1 -- Remote Sensing Physics Test physics of remote sensing with comprehensive description of relevant atmospheric variables; EOS funding needed for field experiments. ARM Cloud and Radiation Testbed (CART) Sites: ARM Southern Great Plains (SGP) CART ARM North Slope of Alaska (NSA) CART ARM Tropical West Pacific (TWP) CART http://www.arm.gov/docs/sites.html

Table 2

CLASS 2 -- Regional Climate Trends
Monitor limited number of critical parameters at surface, combine with MISR/MODIS/ASTER/CERES to accurately describe secular regional changes in radiative forcing (i.e., clouds, surface albedo, aerosols). Surface monitoring MUST include meteorology, broadband SW, LW fluxes and aerosol optical depth; strongly desire PAR, UVB, cloud lidar (to 20 km), aerosol absorbing (physical, chemical) properties, cloud condensation nuclei (CCN). Cloud profiling radar, passive microwave, and high resolution SW spectral measurement of insolation is strongly desired at a signficant fraction of CLASS 2 sites. EOS funding to supplement monitoring instruments at sites established and operated by other agencies; EOS funding for field campaigns.

NASA Langley Walker Tower (Virginia)
75m tower for broadband SW and LW fluxes; aerosol optical depth; standard (4km) laser ceilometer (more range needed)
c.h.whitlock@larc.nasa.gov

NOAA SURFRAD (Surface Radiation Budget Network)
Surface radiation (NIP, PSP, PIR, UVB, PAR); aerosol (MFRSR)
Bondville, Illinois
Fort Peck, Montana
Goodwin Creek, Mississippi
Boulder, Colorado (Table Mountain)
http://www.srrb.noaa.gov/

WCRP BSRN (Baseline Surface Radiation Network)
Use BSRN sites that have surface SW and LW standard flux instruments PLUS aerosol photometer. These sites will probably include:

Station Name	Sponsor	Abbrev.	Lat./Long.	Status
Alice Springs	Australia	ASP	24 S/134 E	s
Manaus	Brazil	MAN	03 S/ 60 W	c
Florianopolis	Brazil	FLO	28 S/ 48 W	Y
Bratt's Lake	Canada	BLA	50 N/104 W	N
Ping Chuan	China	PCH	28 N/102 E	N
Wudaoliang	China	WUD	35 N/ 93 E	N
Aswan	Egypt	ASW	24 N/ 33 E	N
Toravere Observatory	Estonia	TOR	58 N/ 26 E	c
Carpentras	France	CAR	44 N/ 05 E	s
Ny Alesund, Spitsbergen	(N) (Ger.)	NYA	79 N/ 12 E	Y
Lindenberg	Germany	LIN	52 N/ 14 E	s
Georg von Neumayer, Ant.	Germany	GVN	70 S/ 8 W	Y
Budapest-Lorinc	Hungary	BUD	48 N/ 19 E	s
Sede Boqer	Israel	SBO	31 N/ 35 E	N
Tateno	Japan	TAT	36 N/140 E	s
Syowa, Antarctica	Japan	SYO	69 S/ 39 E	Y
Tarawa, Kiribati	New Zealand	TAR	02 N/173 E	N
Pukekohe	New Zealand	PUK	37 S/175 E	N
Al Soodah	Saudi Arabia	ALS	18 N/ 42 E	N
Payerne	Switzerland	PAY	46 N/ 07 E	Y
Barrow, Alaska	USA	BAR	71 N/157 W	Y
Boulder, Colorado	USA	BOU	40 N/105 W	Y
Bermuda	USA	BER	32 N/ 64 W	Y
Kwajalein, Marshall Is.	USA	KWA	09 S/167 W	Y
South Pole, Antarctica	USA	SPO	90 S/000 E	s
Franz Josef Land	Russia	FJL	80 N/ 55 E	N
Billings, Oklahoma	USA	BIL	37 N/ 97 W	Y
Colima	Mexico	COL	20 N/104 W	c
Xilinhat	Mongolia	MON	48 N/110 E	c
Fort Peck, Montana	USA	FPE	48 N/105 W	s
Bondville, Illinois	USA	BON	40 N/ 88 W	s
Goodwin Creek, Miss.	USA	GCR	34 N/ 90 W	s
Boulder SURFRAD, Co.	USA	BOS	40 N/105 W	s

Status: Is station operating?	Key	Number
Yes:	Y	10
No:	N	9

Soon to be established: s 10
Candidate: c 4

Total 33

and eventually ~20 other sites.
http://www.geo.umnw.ethz.ch/wrmc/ [source of above list 8MAR96]

For CLASS 2 "Regional Climate Trend" validation, CERES will employ ~50 sites. It should be noted that (1) the presently planned non-EOS networks like SURFRAD and BSRN may not have adequate coverage of tropical sites in biomass burning regions or deserts, which are critical for testing retrievals of the surface radiation budget and (2) vital supplements to broadband radiometers, such as aerosol photometers, are planned for only a few BSRN sites. Few BSRN or SURFRAD sites will have the needed cloud lidars or SW spectral measurements.

Table 3

CLASS 3 -- Discrete Validation Sites
Use readily available and accurate measurements to validate individual (discrete) EOS products; EOS funding minimal.

100s of airports: laser beam ceilometer LBC (~ 4km) for validation of satellite-based retrievals of cloud base height

BSRN, ISIS, GEBA type sites for surface SW and LW fluxes
BSRN (Baseline Surface Radiation Network) ~ 30-50 sites
ISIS (NOAA Integrated Surface Irradiance Study) ~ 20 sites
GEBA (Global Energy Balance Archive, ETH Zurich) ~ 100s sites

CERES VALIDATION
COMPUTE SURFACE AND ATMOSPHERIC FLUXES

DATA PRODUCTS/PARAMETERS

Broadband SW and LW fluxes
at surface, 500 hPa, tropopause, and TOA
photosynthetically active radiation at surface

Adjustments to cloud, atmospheric, and surface properties
that balance computed fluxes with TOA measurements

MISSIONSTRMM, EOS AM-1, EOS PM-1

APPROACH

Long-term collection of non-EOS surface measurements
Sort observations and CERES products to common format
Issue validating data and products on www
Expand current pre-launch validation activities
CERES/ARM/GEWEX Experiment (CAGEX)
http://snowdog.larc.nasa.gov:8081/cagex.html

3 categories of validation sites with continuous monitoring
Class 1 Remote Sensing Physics
Non EOS programs
Comprehensive measurements - ARM sites
Class 2 Regional Climate Trend
Non EOS programs, but NASA instruments needed
Require surface radiation, aerosols, cloud lidar,
helicopter survey; desire cloud radar
Combine with CERES radiative transfer
Determine regional forcing of aerosols and surface
Class 3 Discrete Validation Sites
Non EOS programs
Individual flux measurements in networks

Extensive aircraft campaign at Class 1 sites

PRELAUNCH

Validation of pre-CERES global Release 1 (October 1986 data)
Compare with other satellite data (i.e., GEWEX SRB)

and available Class 3 sites (i.e., GEBA)

Expand current CAGEX from ARM CART SGP site for GCIP

ARESE October 1995 study with aircraft fluxes and CAGEX
to determine sampling pattern of post-launch flights

Helicopter survey of surface optical properties at key sites
Whitlock spectral SW for MISR/MODIS/ASTER/CERES

POSTLAUNCH

CAGEX to cover all 3 ARM sites

Aircraft fluxes and at ARM sites as needed

Helicopter surveys of selected Class 2 sites (EOS-wide use)

Determine climate forcing of aerosols, surface changes
at Class 2 sites; extend regionally with satellite data

Ship of opportunity with cloud lidar and pyrgeometer
needed for cloud base height, surface LW flux

Supplement oceanography campaigns with surface meas.

EOSDIS

Special processing of CERES data from regions containing
Class 1, 2, 3 sites and for roving ship monitor

Development of CAGEX-like data bases at selected sites

Why have expensive Class 2 sites?

Class 1 Remote Sensing Physics
3 ARM sites
EOS aircraft for vertical flux profiles

Class 2 Regional Climate Trend
~ 50 non-EOS sites
EOS support for instrumentation
--->aerosols, spectral SW, cloud lidar (to 20 km)
aerosol -- see surface with EOS
spectral SW -- check radiation codes
cloud lidar -- screen contrails, thin cirrus
EOS helicopter for surface optics (EOS-wide use)
Get regional forcing of aerosols and surface

Class 3 Discrete Validation Sites
100's of targets of opportunity

Measure with lidar --> screen contrails, whispy clouds

Current EOS: Measure parameters to test models
Improve simulation of climate feedback

Current IPCC: Radiative forcing by trace gases known
What about forcing by aerosols and surface?

Class 2 sites: Use MISR/MODIS/ASTER/CERES to subtract atmosphere
Validate atmosphere subtraction to high accuracy
Separate aerosol/surface signal
Extend site effort (EOS + Class 2)
--> Regional satellite monitoring

Monitor regional changes that sum
to produce global climate forcing

Validate surface ice/snow/bio albedo feedback

With clear-sky SW thus pinned down,
total-sky changes can be ascribed to clouds

What are the trends in surface and aerosol radiative forcing to climate? IPCC needs help here

Suppose EOS measures a small trend in

spectral BDRF (MISR)
aerosol τ (MODIS)
surface-leaving spectral radiance (ASTER)
broadband TOA SW flux (CERES)

Is trend due do changes in surface, aerosol, or thin clouds?

One key to the solution:

EOS plus co-located surface monitoring of A, B, and C

A: Aerosol τ (MFRSR or Cimel)
B: Broadband and spectral surface SW
C: Cloud lidar (cloud base to 20 km)

Radiative forcing changes in surface, aerosol, or thin clouds

EOS plus <u>co-located</u> surface monitoring of A, B, and C

A: Aerosol τ (i.e., MFRSR or Cimel instrument)
B: Broadband and spectral surface SW
C: Cloud lidar (cloud base to 20 km)

A+B: validate EOS aerosol radiative forcing to surface
distinguish surface vs. aerosol changes with EOS

A+C: validate EOS screening of thin clouds, contrails

A+B+C: validate EOS radiative forcing by surface,
aerosol, and thin clouds

---> characterize "clear sky" trends
---> ascribe "total-sky" trends to clouds

A+B needed at ~50 sites
A+B+C needed at ~10 sites